A Synthesis of Oceanic Time Series from the Chukchi and Beaufort Seas and the Arctic Ocean, with Application to Shelf-Basin Exchange

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LONG-TERM GOALS

Our long-term research goals are to understand the physics of the high-latitude ocean mechanistically and quantitatively with respect to both its structure and circulation, as well as to understand the links between those physical mechanisms and the biology and chemistry of the high-latitude marine environment. The variability of that marine environment is a special focus and concern.

OBJECTIVES

Our objective in this work is to analyze existing data from the Arctic Ocean and its adjacent seas in order to:
1) Provide an observationally based indication of the variability of the shelf-basin system;
2) Contribute to focusing and refining the field programs planned under Phase II of the Shelf-Basin interaction initiative (SBI), particularly as these depend upon an understanding of the mechanisms of shelf-basin exchange, and upon the climatology and variability of the shelf-slope-basin system; and
3) Promote further improvements in the rapidly growing array of models of arctic circulation, hydrographic structures, and their variability; and to provide patterns and statistics against which to test the fidelity of these models.

APPROACH

We are conducting a two-year analysis and synthesis of moored time series and other measurements (primarily of velocity, temperature, and salinity) from selected portions of the arctic shelves, slopes, and adjacent deep basins. While the focus is on high-resolution time series, we are also taking advantage of the large hydrographic data base now available.

The geographic coverage of the data set includes the Western Arctic shelves, the continental slope and ridges in both the Eurasian and Canadian basins, and the Canada Basin abyssal plain. The synthesis addresses the circulation and its variability, with an emphasis on the statistics of the measured flows and their temperature and salinity, together with the dynamics that these statistics imply. We will also make this data set widely available through the National Snow and Ice Data Center, Boulder, likely via CD ROM.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE **A Synthesis of Oceanic Time Series from the Chukchi and Beaufort Seas and the Arctic Ocean, with Application to Shelf-Basin Exchange**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,Applied Physics Laboratory,1013 NE 40th Street,Seattle,WA,98105**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

This retrospective study takes advantage of a large data set, the coordinated analysis of which will substantially improve our understanding of the circulation and hydrographic structures of the Arctic shelf-slope-basin system, including their interactions and variability.

WORK COMPLETED

We have completed the analysis of time series from the vicinity of the Lomonosov Ridge and the adjacent Eurasian slope, together with hydrographic data covering both the beginning and end of the mooring deployment period. The hydrographic data provide a regional setting in which to embed the time series, as well as greatly expanded vertical resolution.

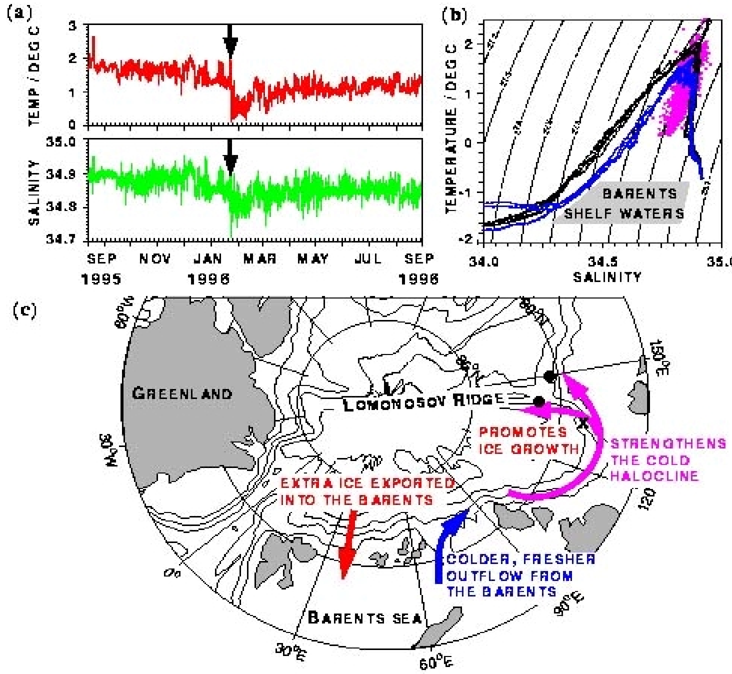
We have already presented a portion of the results at a national meeting, while the remaining portion has been submitted to a second (and later) international meeting via abstract.

RESULTS

The year-long moored temperature and salinity records from three locations spanning the junction of the Lomonosov Ridge with the Eurasian continent show large-scale changes in the structure of the upper ocean, e.g. a sudden cooling and freshening of the Atlantic layer, and a slow warming and salinization of the top of the thermocline which increases the stability of the overlying water. The changes can be traced from the three sites back along the Eurasian Basin boundary towards the St.Anna Trough. We relate these T-S changes, which imply the renewal of the cold halocline layer, to changes in the properties of the Barents Sea outflow driven by an observed increase in the volume of ice entering the Barents Sea from the Arctic Ocean. A counterintuitive implication of this mechanism is that, by stabilizing the upper water column in the eastern Arctic, the export of ice from the Arctic Ocean can inhibit further ice loss through melting (Figure).

Together with accompanying CTD sections, the moored time series also allow quantification of the transport and circulation of the Arctic Ocean boundary current. The flow shows no significant seasonal cycle. Over the Eurasian Basin continental slope (mooring LM1) it is almost twice that observed either on the Eurasian side of the Lomonosov Ridge or over the Canadian Basin continental slope. At all three mooring sites, the current has a similar, equivalent barotropic vertical structure, weakening from top to bottom, e.g. at LM1, from about 6 cm s^{-1} near the surface to near 3 cm s^{-1} at depth. The mean barotropic velocity of about 5 cm s^{-1} is consistent with the advection of changes in the Barents Sea outflow propagating along the Eurasian Basin continental slope and seen in hydrographic sections.

The total transport of the boundary flow, including the warm core of the Atlantic layer, is close to 5 Sv. About half of this is diverted north by the Lomonosov Ridge. Hydrographic sections suggest that some of the northward flowing Atlantic layer also passes into the Canadian Basin through gaps in the ridge south of 88°N, forming an anticyclonic circulation over the southern end of the ridge. A 16 km wide, 1700 m deep gap near 80.4°N allows deep waters to cross the ridge in both directions. In addition to an eastward flow of Eurasian Basin deep water, a small amount (about 0.02 Sv) of Canadian Basin deep water flows westward and is the likely source of an anomalous eddy found in the Amundsen Basin.



Time series (a) in the Atlantic layer at the westernmost mooring (x in (c)) show cooling and freshening in early 1996. On a T-S diagram (b), the spread of the data (mauve dots) shows isopycnal mixing of the warm, saline Atlantic core with Barents shelf waters (grey area). CTD profiles taken before (black lines) and after (blue lines) the cooling and freshening show that the shelf waters also strengthened the cold halocline layer (at salinities near 34.4), reducing upward heat loss and promoting ice growth. Similar changes (not shown) at the other two sites (black dots) in July 1996 are consistent with the shelf signal advecting along the slope and the Lomonosov Ridge with the mean flow observed at the moorings. We estimate that an additional 0.8 Sv of colder, fresher water exited the Barents Sea in winter 1994-1995, when twice as much ice entered the Barents Sea from the Arctic as in the preceding winter. This extra ice, together with atmospheric cooling, likely caused the freshening and cooling. This suggests a feedback mechanism, illustrated in (c), whereby extra ice exported from the Arctic Ocean into the Barents Sea can promote the growth of ice elsewhere in the Arctic.

IMPACT/APPLICATIONS

This work illustrates the spectrum of variability found within the boundary current of the Arctic Ocean, together with a number of the underlying causes of that variability. The work also identifies a new mechanism in shelf-basin interactions, viz., the import onto the shelf of sea ice, and it illustrates the shelf water modification that can result. Furthermore, the analysis provides a measurement-based description of the structure and transport of the boundary current, including the partitioning of the current by the Lomonosov Ridge.

Overall, our work
1) Provides an observationally based indication of the variability of the shelf-basin system necessary to focus and refine the field programs planned under Phase II of SBI, particularly as

these depend upon an understanding of the mechanisms of shelf-basin exchange and upon the climatology and variability of the shelf-slope-basin system;
2) Constrains interpretations of tracer distributions; and
3) Promotes further improvements in the rapidly growing array of models of arctic circulation and hydrographic structures and their variability, and provides patterns and statistics against which to test the fidelity of these models.

TRANSITIONS

Major goals of the SBI initiative are to understand the physical processes responsible for water mass modification over the arctic shelves and slopes and the exchanges with the interior ocean, as well as to understand the variability of this system. Explicit assumptions of the initiative are that arctic shelf and slope processes regulate many of the physical and biogeochemical balances that maintain the present marine arctic climate and ecosystem, and that large changes in the coupled shelf-basin system are possible. Our results address these goals and assumptions directly, and the results will be utilized by other investigators accordingly.

RELATED PROJECTS

New measurements over the Alaskan Beaufort slope funded by the Department of the Interior and the Japan Marine Science and Technology Center include a cross-slope moored array from the same location as measurements being analyzed under the present ONR-sponsored effort. The new measurements are being made under the direction of T. Weingartner of the University of Alaska, and comparison with these measurements is important to understanding the boundary current north of Alaska and western Canada and its variability.

Ongoing work in the Canadian Beaufort Sea under the direction of E. Carmack of the Institute of Ocean Sciences (IOS) in Sidney, B.C. includes the longest time series available from the Arctic Ocean. Together with a variety of tracer and hydrographic measurements. To take advantage of the Canadian data and expertise, we are working with IOS investigators in our synthesis efforts.